**DESIGN OF AN AUTOMATED WELDING PROCESS FOR *SYNERGY MFG.***

**A Senior Project submitted to**

**the Faculty of California Polytechnic State University,**

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**by**

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**ABSTRACT**

DESIGN OF AN AUTOMATED WELDING PROCESS FOR *SYNERGY MFG.*

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This senior project involves a partnership with a local off-road parts manufacturer called Synergy Mfg. Synergy is experiencing a rapid increase in demand that is difficult to meet with their current processes. Because of this issue, Synergy is exploring automation in order to decrease their cycle times and increase their production output. More specifically, this report concentrates on automating a manual welding process that has a lengthy cycle time which causes Synergy's difficulties with meeting demand. Due to time constraints, this project focused on the automation of a welding process for only one part that Synergy produces. This part contains intricate weld patterns that result in a prolonged cycle time. In addition to this, the only automation resource available is a Fanuc 50iD ARC Mate welding robot. This particular robot is used widely in production and will establish a conclusive baseline for most automated welding equipment.

A fixture was first developed and produced that is compatible with the available welding robot. Because the development of a fixture involves many other considerations and variables, this project was divided into two. The first project of developing a welding fixture was completed by Joe Hanacek and can be referenced if more information regarding the fixture is needed. This report is a continuation of Hanacek's project.

Moving forward, a program was written and numerous parts were welded. From this trial production run, it was found that the automated cycle time resulted in a 30.2% improvement compared to the manual cycle time. Along with this improvement, the cost of labor was decreased but not eliminated because the robot used in this project still required an operator but not a skilled welder. After further analysis, it was determined that with the ideal conditions, implementing a robot welder may potentially increase Synergy's yearly output by 43.1% and require a payback period of roughly 52 weeks.

It was concluded that implementing a welding robot will ultimately help Synergy's difficulties with meeting demand. The recommendations with this conclusion involve professionally manufacturing a fixture rather than using the rough prototype involved in this project. The rough prototype lead to many defects due to incomplete construction and lack of clamping force needed to securely hold the part. Also, most of the welds in the trial production run were visually inspected and passed but did not undergo any thorough break tests. It is recommended that Synergy conducts break tests on the welds in order to verify the weld strengths.

**Notice:**

This report is a continuation and collaboration with a published senior project by Joe Hanacek. The first 21 pages are borrowed heavily from Hanacek's report.

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## I. Introduction

The world's population is increasing at a rapid rate and with this, the demand for products is escalating. Factories face many challenges such as maintaining production rate, quality, and consistency with upscaling production to meet demand. These challenges have pushed for the development and integration of manufacturing automation. Automation has proved to be successful and is being integrated more and more in today's world. The subject of this report is to analyze and overcome the challenges faced with integrating automation into manufacturing along with performing a cost analysis in order to determine the overall benefit of automation integration.

This project is working with a company called Synergy Mfg., an automotive off-road parts manufacturer. "Synergy Manufacturing is an industry innovator and manufacturer of high-end automotive performance components." Currently, Synergy manually welds all of its parts and does not have an automated system. With Synergy's growing demand, they are exploring the benefits of implementing a welding robot in order to automate their welding process. A welding robot requires research, programming, fixture design, and an overall cost analysis in order to be successfully and beneficially be implemented.

Cal Poly has a Fanuc welding robot in their IME lab that has not successfully executed a full production run. This report will utilize this equipment and establish a baseline for all robots that Synergy may take into consideration. In order to successfully provide data for Synergy, the following objectives must be accomplished in this order:

- Determine a worthy part that Synergy manufactures in high volume and use it for this report.
- Design an automated welding process that takes the following into consideration: cycle time, repeatability, labor costs, start-up costs, operator interaction, and welding parameters.
- Successfully weld simple parts with the Fanuc robot and analyze the quality and speed.
- Successfully program the Fanuc arm to weld the chosen part with the prototyped fixture.
- Perform a cost analysis using cycle times, quality, and strength of the automated process versus the manual process.

First of all, in order to learn how to operate and program the Fanuc arm, an extensive amount of research will be required. The accessible sources for this report includes manuals, individual references such as professors and Fanuc representatives, online journal articles, and the engineering problem solving skills that has been learned through Cal Poly. With this gained experience, simple parts will be tested to determine the feasibility, quality, and speed of the welds.

Next, through discussions with Synergy, two ideal parts have been chosen for this study. One of the parts is a track bar brace that is attached to the chassis of a vehicle that requires five separate welds. The second part is a steering stabilizer relocation Bracket which requires only two welds. Synergy produces both of these parts in high volume making them an ideal candidate for this study. The parts do not require underside welds making it more simple to create a successful program. Additionally, with these selected parts, a fixture must be designed and manufactured considering the capabilities of the Fanuc arm along with the cost, desired tolerances, and production volume that Synergy intends to achieve. This was done through a separate senior project. In order to take the Fanuc's capabilities into consideration, multiple measurements and movements must be explored.

For one of the final steps in this report, the experience and knowledge obtained from the first objective of researching how to program the Fanuc arm will be utilized to create a successful and efficient program. A baseline will be established through the examination of Synergy's current process. With the acquired data from this baseline, a program will be developed in order to achieve an efficient cycle time and acceptable quality. Once this program is complete, a cost analysis will be done in order to determine the benefits of implementing a robot in Synergy's production. This will be done by conducting time studies and visual quality inspections of the designed process for the robot.

Overall, the deliverables will include a cost analysis, data extracted from a successful program executed through a trial production run, and recommendations for Synergy on how to successfully integrate a welding robot into their production process. The cost analysis along will help Synergy make a decision of purchasing and implementing a welding robot. The data extracted from running the program will also be provided to Synergy in order to assist them with the operation of their potential future robot. Finally, recommendations will be verbally discussed with Synergy in order to assist them in their future process of implementing a welding robot.

## II. Background (includes **Literature Review**)

This section will cover background information that is necessary to help understand the methods and findings presented in this paper. This section includes information about the company, the robot used, fixture design, weld settings, how automation is used, automation's effect on quality, the costs related to automation, safety related to automation, and finally past research related to this project.

### *2.1 Synergy:*

Synergy Manufacturing designs and manufactures high-end automotive performance components based out of San Luis Obispo, CA. They have a wide variety of products that are designed for vehicles such as Jeeps and Dodge Ram Trucks. Synergy has been manufacturing parts since 2005 and through the years they have added on more products and the demand for their products is rapidly rising. With this increase in demand, Synergy is looking for ways to increase throughput. Synergy's current manufacturing process uses all manual welding requiring employees to perform repetitive motions that could lead to inconsistencies due to human-errors. Synergy has already started looking at different automated welding systems, but they need to assess if it will be cost effective as well as decide which system would work best with their products. Space, cost, ease of use, and scalability are considerations that should be taken into account when looking at viable automated welding systems.

### *2.2 Welding Robot:*

This project involves using a Fanuc ARC Mate 50iD welding robot to automate a welding process in order to perform a cost analysis and see the potential benefits of automated welding. The Fanuc arm utilizes an R-30iB Mate Cabinet controller system that provides easy-to-use motion control functions in a compact, energy efficient platform. The arm can be programmed utilizing both online and offline programming, however this project will only involve online programming. Online programming utilizes a teaching pendant to move the arm in real time and record motions for the controller system to memorize and follow later. The Fanuc welder is located on Cal Poly SLO's campus and has not successfully executed a full production run. Utilizing lessons from Lincoln Electric, a program will be created to best fit the needs of Synergy's product [10].

### *2.3 Automated Welding Fixture:*

A fixture is used in manufacturing to securely locate a part in such a way that promotes ease-of-use and ensures that important tolerances are met. Fixtures help make a process repeatable by having consistent placement of the part. There are differences between machining fixtures and welding fixtures. The biggest difference is that a welding fixture needs to hold each component that will be welded without interfering with the welding gun or torch. Welding fixtures also need to resist high heat and sputter, permit passage of weld runoff, and in some cases conduct electricity and provide grounding [14]. For automated welding, the fixture should strive for accessibility, repeatability, simplicity, and dependability [14]. The fixture needs to be consistent in the placement of parts as well as the placement of the fixture in the welding robot's enclosure. If the placement of fixture and part is not repeatable, there is no way for the Fanuc arm to located it and will result in out of tolerance parts. In order to decrease lead time, the fixture needs to be simple to load parts so that the operator can easily and quickly load and unload parts.

### *2.4 Weld Settings:*

Weld strength is influenced by materials, temperature, speed, torch angles, voltage and current, distance from workpiece, and wire-feed speed. There is no optimal setting that works for all materials, therefore trial-and-error tests are needed to optimize weld strength. There is plenty of information that can provide baseline settings for the type of material that will be welded.

There are multiple studies and articles that determine optimal weld strength for a variety of processes. In the book, *Welding Science and Technology* by Ibrahim Khan, the most important factors to keep in mind in order to achieve optimal welds are: a source of energy to create union by fusion or pressure, a method for removing surface contaminants, a method for protecting metal from atmospheric contamination and a control of weld metallurgy [7]. Additionally, a study done by the Indian Institute of Technology Kharagpur discusses pulsed MIG torch angles effect on weld joint strength. In the study, they demonstrated how torch angles influence mechanical properties. After conducting a series of tests, they found on average perpendicular welding resulted in the highest joint strength [6]. A similar article discussed the effects of torch position and angle on the quality and welding process stability of a brazing application for pulse on pulse MIG welding. In this article they found that a travel angle of 20 degrees with a work angle of 20 degrees was optimal for striking an arc as well as maintaining the arc [8]. In a paper from Durham University they found that as welding speed increases temperature decreases in the fusion zone, but has less effect to the areas outside the fusion zone and heat affected zone [5]. These sources provide insight into related past topics. They will serve as a starting point for this project.

### *2.5 Automation:*

In industry today there is a huge push for automation. This trend is not seen in just one field; automotive companies like Ford and Toyota benefit from a high level of automation, toy companies like LEGO, and even biomedical companies like Applied Medical. These very different fields all have automation in common for very good reasons. Automation can improve product quality, increase labor productivity, reduce labor cost, mitigate the effects of labor shortages, reduce or eliminate routine manual and clerical tasks, reduce lead time, and improve worker safety [12]. All these benefits fall into three categories; increase quality, decrease cost, and improve safety.

Additionally, with such a large population in today's world, product demand fluctuates unpredictably and significantly. With these fluctuations, companies must adapt quickly in order to make frequent product and process changes that will keep the company ahead of the game. This is called, Agile Manufacturing. Agile manufacturing is difficult and tends to be costly and timely. One approach that companies are taking is the implementation of manufacturing automation. A.C Deuel, a manufacturing manager, states in his article, *The Benefits of a Manufacturing Execution System for a Plantwide Automation,* that in order to execute manufacturing agility successfully, manufacturers must implement automation in their production processes [4]. With this growing demand fluctuation, manufacturing automation proves to be a sufficient solution for companies in order to maintain their competitive edge.

Overall, many companies have utilized the benefits of automation. This allow companies to meet demand with quality. “The implementation of industrial robots in SMEs was an increasing trend in the previous decade and still is” [13]. Tesla, a revolutionary automobile manufacturer, aims to automate their facilities more and more every year. Of course, automation is not simple and requires robot calibration, programming, production scheduling, selection of robots, and welding support. Depending on the volume of production, quality required, and cost, many factors must be taken into consideration when implementing a robot in production.

### *2.6 Improving Quality:*

Mass production requires a well-designed repeatable process to ensure a quality product. Using manual labor for a large volume part requires personnel to perform the same tasks over and over again, this repetition is bound to lead to inconsistencies. These inconsistencies are caused by human-error and can result in high scrap rates or even worse, product recalls. These quality issues can cost a companies a fortune and are usually caused by an unrepeatable process. Using automation, the chance of human-error is significantly decreased. This is due to the fact that automated systems do not fatigue like human workers do. This allows for more consistent and repeatable steps in a company's process increasing the quality of the product. But, consistency and repeatability isn’t enough to ensure quality, it requires that each step in the process is performed with precision.

In many industries, production of parts requires skilled personnel to perform tedious and arduous tasks. Some of these tasks can't be performed with a manual labor process. An article written by J. Liburdi, P. Lowden, and C. Pilcher discusses the difficulties affiliated with welding turbine blades. In this situation, the welds required joining super alloys that are prone to micro-cracking. The article states that the process requires "the highest degree of welder skill and discipline" and in some cases, the welders could not achieve satisfactory results [9]. This issue was resolved through implementation of an automated welder that could be programmed to precisely match "the complex airfoil shapes and the welding parameters" to result in better metallurgical quality [9]. The article shows that a process that has inconsistent results experienced better product quality by implementing automation. This and other increases in quality leads to higher customer satisfaction and lower production costs.

*2.7 Reducing Cost:*

Every company's goal is to increase their profits which can be accomplished through a reduction in their costs. The cost of manufacturing is influenced by quality, lead time, labor, processes, etc. Decreasing lead time allows a company to become more lean through decreasing WIP, work-in-progress, and inventory. With a short lead time, a company can move in the direction of a just-in-time inventory strategy. This pull inventory strategy is difficult to achieve, however, it is a cheaper option and requires less space than the more common push strategy which requires accurate demand forecasting and large storage spaces. Along with inventory costs, there is the cost of labor. One way to reduce labor costs is to fire employees, however, this is not an option for many companies as they are already struggling to meet demand. Another option is to replace labor by implementing machines that can perform manual labor tasks [12]. This option requires a change in the manufacturing process.

In order to program a robot, a qualified and educated individual must be responsible. The pay rate and labor of this individual must be taken into consideration when assessing the benefits of a welding robot. “One of the major parameters when using robot welding is the estimation of programming time” [13]. Depending on production batches and volume, programming time must be taken into consideration. For example, if a company’s factory is set up more like a “Job Shop,” a facility that specializes in high product variety, the length of programming time of a new part may outweigh its benefits. On the other hand, a facility that has large batches such as Synergy, may find it to be very beneficial to implement a welding robot. High volume production requires repetitive motions and consistent quality, both of which are offered by a robot.

There are many ways to improve a process, but they can all be summarized with the lean principle of removing waste. This can be done by floor layout, removing non-quality adding steps, as well as reducing rework and scrap through implementing more consistent and repeatable steps. A study published in "Volume 4: Transdisciplinary Engineering: Crossing Boundaries" focused on reducing cost of spark plug manufacturing through decreasing quality defects that lead to rework and scrap. In their research they found that each quality defect was caused by improper contact of the cables. To solve this issue they implemented an automated spark plug pressing system that ensured consistent cable contact. By solving this quality issue they reduced cost by "nearly $6,500 (six thousand five hundred dollars) " a year [2].

### *2.8 Safety Through Automation:*

With the enactment of the Occupational Safety and Health Act (OSHA), employee safety has become a huge priority [12]. There are many ways to improve employee safety, but one that is usually overlooked is automation. This safety benefit is not solved by simply automating a step, there are parameters that must be met to ensure worker safety. Implementing automation can be dangerous compared to manual processes; manual processes rely on the operator to be in charge of promoting safety, but with an automated process there needs to be safety parameters built into the system. An article comparing manual machining to CNC machining showed that through the automation of the CNC technology, there was a reduction in the risk of injury lowering the level of accidents. This was done by implementing failsafe controllers in the system. The article went on to explain that this wasn't because of removing the operator from the machining, it expressed that the true improvement to worker safety was caused by the machine's safety parameters. These safety parameters include going into a fault state if the doors are open or notifying the operator if a tool breaks. All of the parameters together helped poka-yoke (fool-proof) the CNC machine so that when an accident occurred the machine would stop [11]. This article shows that by simply automating a step, it does not ensure a safe workplace, the automated system needs safety parameters that will ensure that if an operator is in danger, the system will stop before any harm is caused.

### *2.9 Past Work in Similar Fields:*

Past fixture ideas for welding robots include something called “Flexible Fixturing.” A flexible fixture is a fixture that can be customized for a wide variety of parts. Instead of having one fixture dedicated for a single part, a flexible fixture allows many different kinds of parts to be welded with an automated welding process as seen in figures 1 & 2 below.

*Figure 1 [3]*

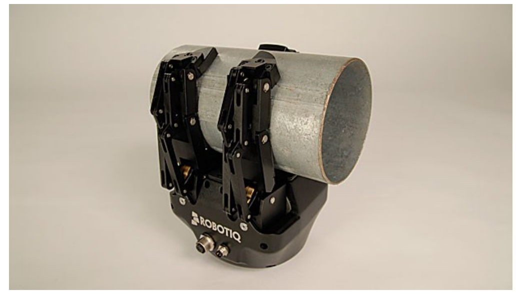


*Figure 2 [3]*

Companies have to make quick product changes increasing the demand for flexible fixtures [1]. This allows companies to maintain a competitive edge with new products and adapt to demand fluctuations.

A company called "Robotiq," developed this gripper that allows many different products to be fixtured in order to be automatically welded. The gripper has high strength ensuring a secure hold for a variety of parts. The high strength also allows for precision helping to meet the desired tolerances. This precision is achieved due to the strong hold on the parts which helps reduce vibration and movement during the actual welding process. Along with the high strength this gripper fixture is very durable allowing for high volume production [3].

The idea presented by this flexible fixture may potentially motivate Synergy's final fixture design in order to accommodate a variety of parts. This is because If Synergy purchases a $75,000 robot, logically, they do not want to assign it to only one part to weld. Designing a fixture that is somewhat flexible for this report will benefit Synergy in the way that they are not obligated to weld one part with the robot. Instead they can assign any part with the current highest demand. This article sparked up a new idea for the project. When it comes to manufacturing, the goal is to utilize machines to ensure a consistent and quality part. When it comes to an expensive robot, you want to make sure that you can utilize it as much as you can meet the demands for different products. Now for the fixture design, elements from flexible fixture design can be implemented to fit a wide range of products.

## III. Design

For this project, Hanacek's fixture design will be used in order to design an automated welding process which includes the programming of the Fanuc. This section will discuss the two facets of the project; Fixture/Part used for this project, and the Process Design. It will cover all the important considerations made during this project, focusing on the Fanuc arm's capabilities and limitations.

*3.1 Synergy's Current State*:

Synergy's current welding process consists of only manual operations. The track bar brace begins as 3 separate pieces as shown in figure 3 below.

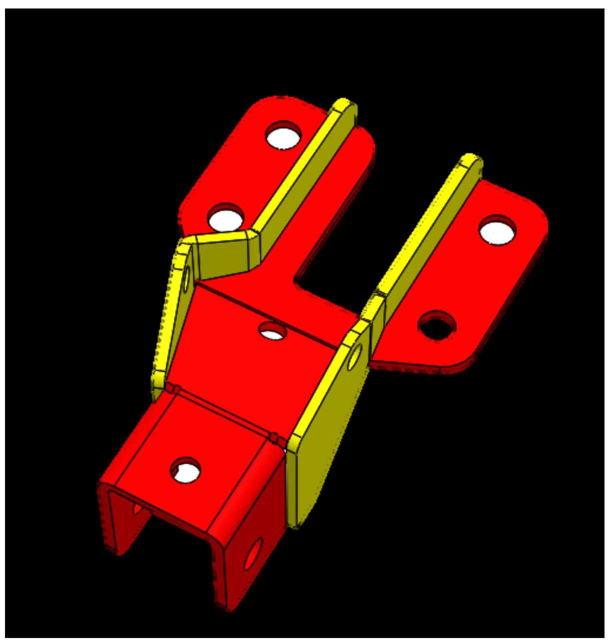


*Figure 3*

Each of the 3 pieces are placed, located, and clamped manually in order to weld. The welding process begins by spot-welding each piece together. This allows a secure hold and ensures the proper location of each piece avoiding the process of having to relocated each part if they are knocked loose. Once all of the parts are spot welded, the final welds are completed. You can see the whole process as shown in the flowchart below.

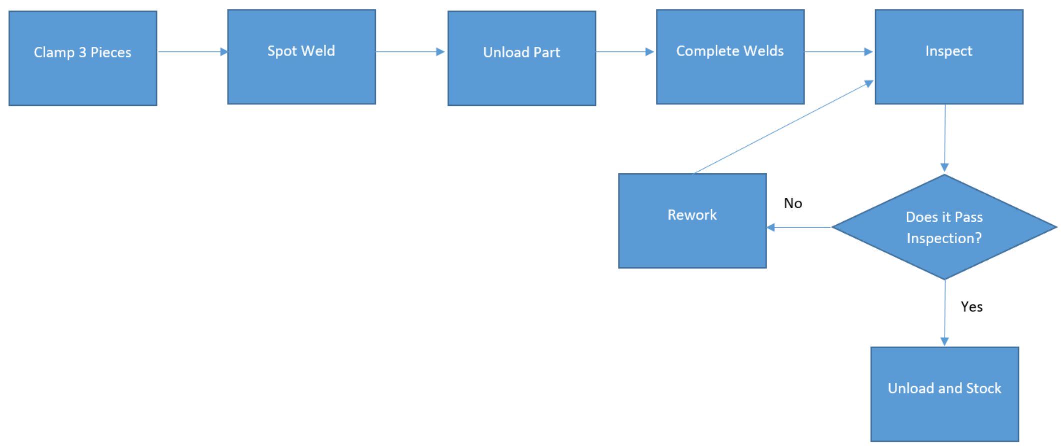



*Figure 4*

With this current process still in place, Synergy is beginning to experience some issues with meeting demand. During 2016, Synergy had a demand of 5,000 parts per year and during 2017 their demand has increased to 600 parts per month and is estimated to be about 30% more than the demand in 2016 with a final estimated demand of 7,200 parts for the year. Synergy's current process lacks the abilities to meet this rapidly increasing demand due to the lengthy manual processes. According to Joe Hanacek's studies as shown below, the total process time takes about 4 minutes and 21 seconds. For this project, the focus will be on the manual welding which includes Tack, Unload, and Finish weld. These processes take total time of 3 minutes and 30 seconds to complete.

| Steps | Avg. Times Current State |
|---|---|
| Clamp | 00:41.7 |
| Tack | 00:26.2 |
| Unload | 00:17.1 |
| Finish Weld | 02:52.6 |
| Inspect | 00:04.0 |
| **Total** | **04:21.6** |

*Table 1 [16]*

### *3.2 Fixture/Part Design:*

In order to develop a fixture based on the part provided by Synergy, the proper datums must be located along with the desired tolerances by the fixture. This will allow the part to be welded meeting the specifications that Synergy requires. Once the necessary and important dimensions are determined, the design of a fixture that can locate and hold the parts for consistent welds can be created. The parts need to be easily loaded and unloaded as to minimize lead time. Along with this, the way the parts are fixtured for welding cannot interfere with the toolpaths of the Fanuc arm. The materials must withstand the high temperatures and sputter caused by welding. And finally, there needs to be consistent loading of the fixture in the welding enclosure so that the Fanuc arm can consistently find the home location to begin each weld.

Below you can see the fixture that resulted from Joe Hanacek's senior project. Taking into the considerations mentioned previously, Hanacek developed a fixture that properly locates the crucial part datums, offers sufficient clamping forces to prevent the pieces from getting knocked out of location, materials that can withstand the heat from welding, and finally a design that does not interfere with the movements of the Fanuc arm. Figure 5 shows the final CAD model of the fixture while figure 6 shows the rough prototype used in this project. You can see that the prototype does not include all of the clamping mechanisms which resulted in a lack of clamping force that caused some issues later in the project. Please reference Joe Hanacek's senior project, *WELDING PROCESS REDESIGN FOR PRODUCTION OF TRACK BAR BRACE,* to acquire additional details regarding the fixture.

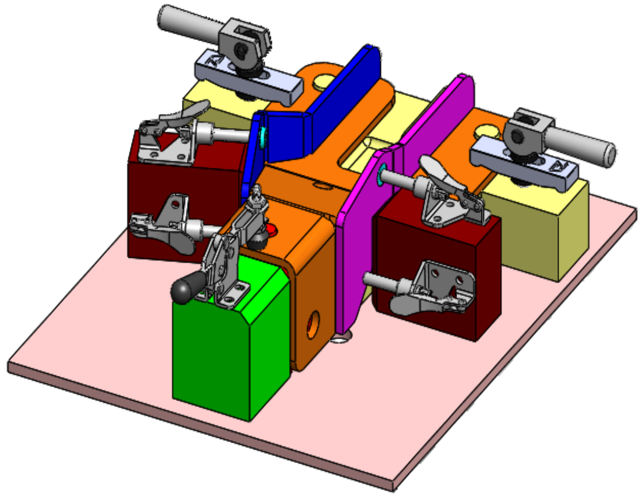


*Figure 5*

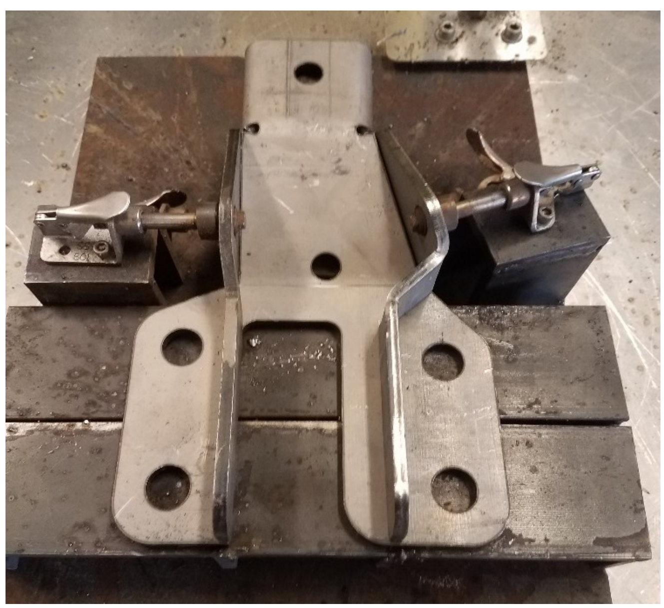


*Figure 6*

*3.3 Process Design:*

The first objective in the process design will include a functional program for the Fanuc arm. This functional program needs to work with the design of the fixture and the limitations of the Fanuc arm. The limitations presented from the Fanuc arm include factors such as workspace and arm mobility. These limitations are caused by the available space within the enclosure and the chance of the arm binding under certain movements. The figure below represents the top view of the shape of the enclosure for the robot.

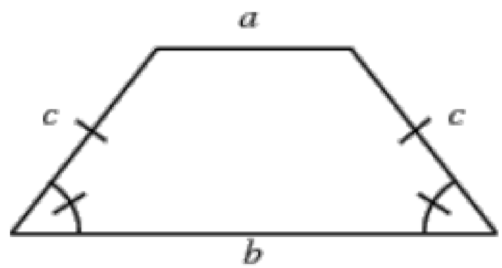



*Figure 7*

As you can see, the shape of the robot enclosure is a trapezoid. This may possibly limit farther movements of the robot as it reaches the edge of the enclosure. Rough measurements determine the length of the enclosure from “b” to “a” are about 2 feet. The dimension a is about 23 inches and dimension “b” is about 60 inches. These measurements are well beyond the requirements for the parts that are to be welded in this project. The biggest part being roughly 8 inches in length and 2 inches in height, will fit perfectly in the enclosure.

The robot will be programmed using a teaching pendant in an online mode, meaning the robot will be powered on when inputting commands. The teaching pendant consists of numerous buttons in order to navigate through the robot's functions. The figure below depicts the layout and different buttons for a Fanuc robot teaching pendant.

*Figure 8*

Creating a program for the Fanuc will consist of inputting two positions and having the robot jog between those two positions. Once the robot has completed its path, a program is generated for that specific tool path. The robot also has two options of coordinate systems, world and local. For this project, the local coordinate system will be used. The procedure for creating the suitable program around the part and fixture will incorporate the following: small path movements in order to ensure precision, logical positioning of the robot arm so it will not have to reset itself after each movement, and speed of each path to ensure the welds meet specifications.

### *3.4 Determining Optimum Process Parameters:*

When it comes to implementing a new automated process, there are a lot of variables that must be taken into consideration. For this project, the main variables that were focused on were the welding parameters along with taking into consideration the interaction between the operator and the equipment.

One overlooked variable, robot movements, must be executed strategically and efficiently in order to minimize cycle time. For example, repositioning the robot to gain access to another weld must be done minimally in order to reduce all wastes than can be caused by excess movement. If the robot is executing unnecessary movements, it can add to the cycle time defeating the main purpose of reducing a cycle time when implementing an automated process. The Fanuc used in this project contains two different types of movements, linear, and arc paths. For this process, linear paths were used due to the lack of circular geometries of the track bar brace chosen for this project. It was determined that with the use of arc path movements, cycle time can be increased due to the extra distance traveled when executing an arc path versus a linear path. A linear path travels the shortest distance between two points while an arc path adds extra distance between the same two points due to the arc movement. The project moved forward with this in mind and the program was written using only linear movements.

Next, the welding parameters consist of adjustable numerical values that change the consistency of the weld. In this case, the variables are feed rate (Inches per Minute), Power (Voltage and Amperage), and Travel Speed (Inches per Minute). In order to produce an optimum weld based on these specific parameters, numerous trial-and-error runs must be completed. Before these trial-and-error runs, research and calculations were done through the *Miller Electric* website resulting in the feeds and speeds below that should be used:

Wire Feed Speed: 360 – 380 ipm

Voltage Range: 21 – 22 Volts

Amperage Range: 180 – 190 amps

These calculations do not include travel speed because that is in the hands of the manual welder for a non-automated welding process. For this project, the travel speed must be quantified within the robot and determined through a series of trial-and-error runs. The travel speed of the robot can influence a few resulting factors of the welds. For example, if the welder travels too quickly, it can result in a smaller weld meaning that there was not enough material deposited. This can also result in lack of penetration of the weld causing the part to not meet strength requirements. On the other hand, if the travel speed is too slow, it can cause excess material to be deposited but more importantly, this can cause too much penetration of the weld sacrificing the strength of the part. So, there must be a median value that can cause enough penetration of the weld along with depositing enough material based on the required specifications of the part. These same principles apply to the wire feed rate of the welder as well.

The power of the welder can result in the lack of weld penetration, or excessive weld penetration. Usually, power is measured in amperage and voltage separately but for this project, the Fanuc 50iD uses numerical values for both voltage and amperage grouped into one numerical value.

Finally, operator interaction can influence a process in many ways. In this case, loading and unloading the part can cause excessive cycle times that may defeat the purpose of automating a process. It was discovered that there still will be some human interaction if a robot welder is implemented. There must be an operator beginning the weld cycle along with loading the parts into the fixture. If the fixture is too complicated, the operator can spend too much time loading the parts. In addition to this, fortunately the Fanuc is easy and quick to use so operator interaction with the machine was not a big addition to the cycle time.

## IV. Methods

*4.1 Determining Welding Parameters:*

In order to test each parameter on the Fanuc, test plates were welded and visually inspected in order to determine the effects of each parameter. Initially, the method used to execute each weld was a preset list of parameters that are already programmed in the robot. Below in figure 9 you can see the results of this preset weld setting.

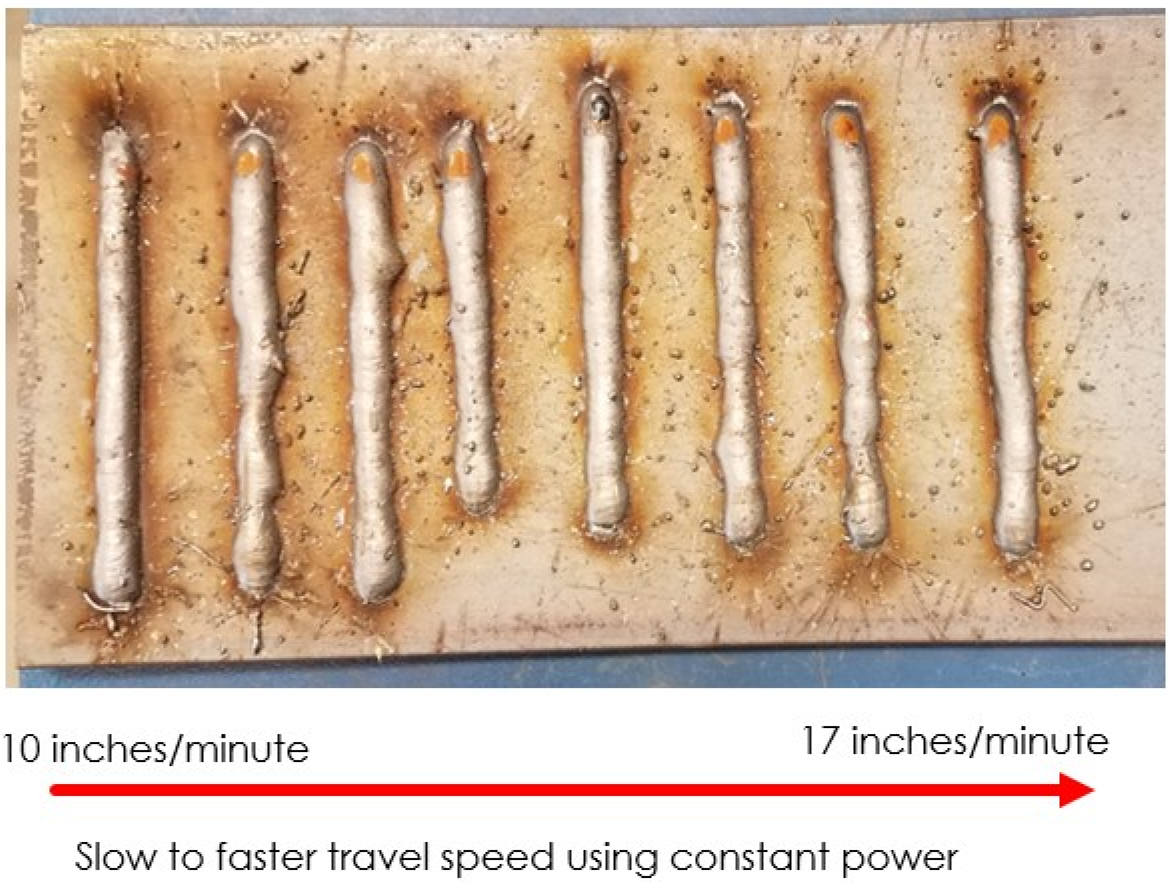



*Figure 9*

With this weld setting, the only parameters that can be adjusted are feed rate, and travel speed. The power stayed constant with the preset parameters programmed in the robot. The feed rate was kept constant with these welds at around 350 inches/minute while the travel speed was adjusted gradually from 10 inches/minute to 17 inches/minute. On the left most weld in figure 9 you can see the slowest travel speed was used at 10 inches/minute. This resulted in a satisfactory amount of material deposited but still lacked the penetration required to pass the part structurally. Moving to the left most weld in figure 9, there is no significant difference between the welds. It was determined that in order to achieve the desired weld quality, the power must be adjusted. Further weld commands were discovered that allowed the adjusting of all three parameters, feed rate, travel speed, and power, that allowed the Fanuc to achieve optimum welds.

It was then discovered that the Fanuc teaching pendant contains a customizable weld setting with different schedules that can be called out for each weld that is desired. The schedules allow you to adjust power in addition to wire feed rate and travel speed in which the previous weld setting mentioned was incapable of. Below you can see the list of schedules called out for the final program in figure 10 and the resulting welds in figure 11.

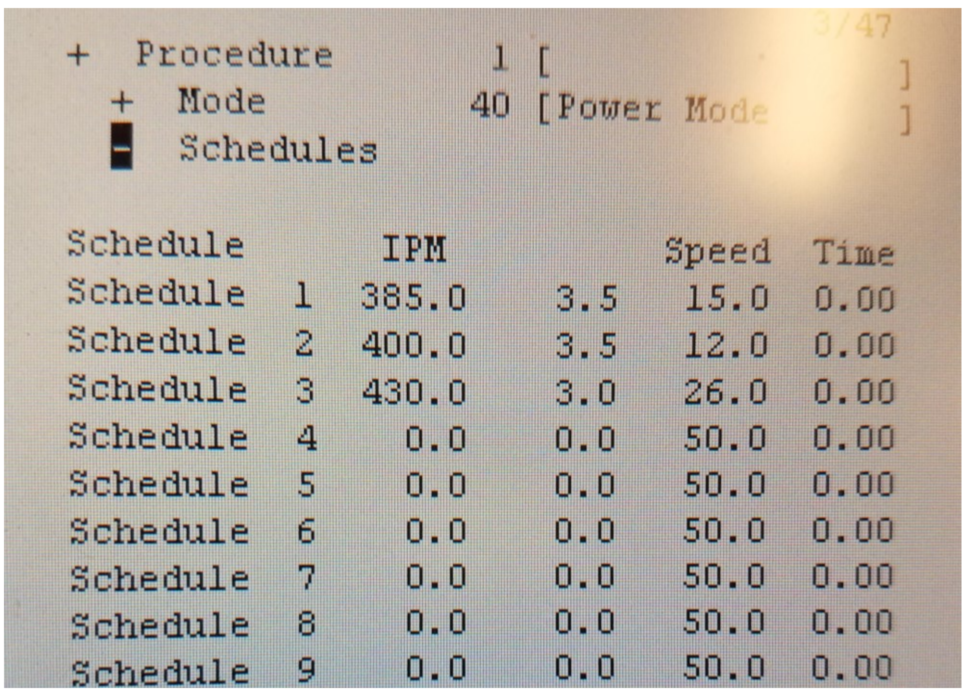


*Figure 10*

More power, same travel speed

*Figure 11*

With the flexibility to adjust all 3 parameters, the desired results were achieved quickly. Ignoring the two left welds in figure 11, poor quality welds due to the shortage of shield gas, the optimum weld was achieved which is circled in yellow in figure 11. This final weld was visually inspected and passed by a welding instructor. The characteristic of these welds were deep penetration, proper amount of material deposited, and even consistency. It was concluded that this welding setting will only be used to write the final program due to the excellent results.

## *4.2 Developing the Program:*

The Fanuc 50iD contains a program language similar to G-Code. The program consists of different coordinates signaling the robot to move from the one point to another sequential point. The movement from point to point can be programmed in a linear or arch path as mentioned before. The linear path determines the quickest way from point to point and the arch path involves entering in a radius signaling the robot to move in an arch path between the two points.

Figure 12 below shows the two sets of points that were used in the final written program. The “P [#]” contained in both 1 and 2 means that these lines of code are point inputs and the number between the brackets represents the point number. The difference between the two points shown in figure 12 are that 1 is simply calling out the speed of the robot, hence the 100%, and 2 is calling out a specific travel speed, 15.0inch/min. Line 1 was used for air moves in order to reposition the robot quickly. Since line 2 offered the flexibility to adjust travel speed, it was used for welding only.

```
1. 1:J   P[1] 100% FINE

2. 8:L   P[8] 15.0inch/min FINE
```

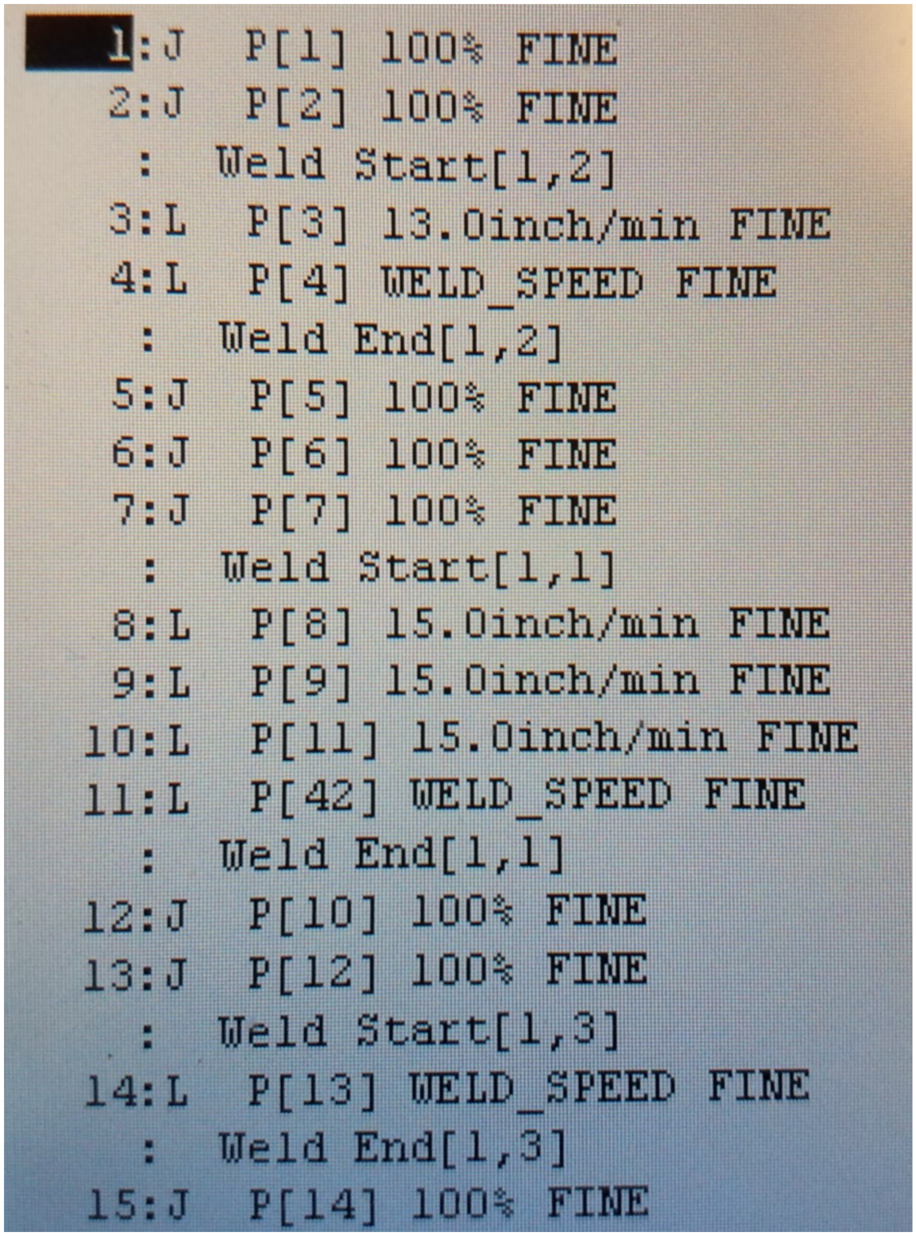
*Figure 12*

Next, in order to command the robot to begin a weld, a point must be entered along with the command “Weld Start” as shown in figure 13 below.

```
2:J   P[2] 100% FINE
  :   Weld Start[1,2]
```

*Figure 13*

As you can see, the point command is still present in the first line after “2:” and the only addition to begin the weld is the command “Weld Start” in the second line. The numbers after “Weld Start” represent the schedule called which allowed the flexibility to adjust the robot’s welding parameters as stated previously. This was the only weld command used to write the final program.



```
 1:J  P[1] 100% FINE
 2:J  P[2] 100% FINE
   :  Weld Start[1,2]
 3:L  P[3] 13.0inch/min FINE
 4:L  P[4] WELD_SPEED FINE
   :  Weld End[1,2]
 5:J  P[5] 100% FINE
 6:J  P[6] 100% FINE
 7:J  P[7] 100% FINE
   :  Weld Start[1,1]
 8:L  P[8] 15.0inch/min FINE
 9:L  P[9] 15.0inch/min FINE
10:L  P[11] 15.0inch/min FINE
11:L  P[42] WELD_SPEED FINE
   :  Weld End[1,1]
12:J  P[10] 100% FINE
13:J  P[12] 100% FINE
   :  Weld Start[1,3]
14:L  P[13] WELD_SPEED FINE
   :  Weld End[1,3]
15:J  P[14] 100% FINE
```

*Figure 14: Snapshot of Final Program*

## V. Results

### *5.1 End Results vs. Requirements and Expectations:*

With the final weld settings and program commands determined, the program in order to weld the track bar brace for this project was written. The initial step was to run a lot of 10 parts in order to determine quality and effectiveness of the weld parameters. The results of the program did contain one bad weld as shown in figure 15 below.

*Figure 15*

After running the 10 parts, every single part contained this defective weld. The positioning and parameters were adjusted in order to attempt to achieve the optimum weld. Unfortunately, none of these parameters that were adjusted resulted in a proper weld. It was later concluded that the rough prototyped fixture was the main issue causing these defects. This was due to the lack of clamping and location of each part after every cycle. This lack of clamping force caused a gap between the 2 pieces in figure 15 above. When having a gap in any welding process, achieving the proper weld is extremely difficult and requires intricate movements and positioning of the welder, something that was difficult to accomplish with the Fanuc 50iD.

This defective weld was obviously out of spec and did not meet the design requirements that Synergy expected. Once it was concluded that the fixture was the issue behind this, a few adjustments were made in order to successfully run the second lot of parts. The new adjustments were kept simple due to the lack of resources available to manufacture another better quality fixture. Although this would never be acceptable in a real production process, for every piece that was inserted into the fixture, adjustments in location were made in order to line up the gaps properly. After implementing this change mimicking a better quality fixture, the second lot of parts resulted in better quality welds as shown in figures 16 through 18 below.

*Figure 16*

*Figure 17*

*Figure 18*

The results of this new process step that was intended to mimic a better quality fixture resulted in 9/10 welds successful welds. These welds were determined successful through visual inspections conducted by a welding professor along with Synergy themselves. In the previous lot of ten, 0% of the parts were passed but after implementing the new step in the cycle, 90% of the parts were successfully passed.

Moving forward with these results, the new automated cycle time was a 30.2% improvement, 2 minutes and 30 seconds, compared to the manual welding cycle time which was 3 minutes and 30 seconds. This was due to the elimination of the extra process of tack welding the pieces together along with the robot's movement flexibility that did not require any repositioning of the part, something that the manual welding process required.

Overall, with fine tuning and professional fixture fabrication, the automated welding process prevailed. Again, this was due to a shorter cycle time and elimination of extra steps that are required in the manual welding process. Along with this benefit, the automated welding process was very consistent. This was determined through visual inspection. It was concluded that all of the welds were completed consistently even though there was one defective weld that was apparent in every part.

### *5.2 Design for Manufacturability:*

Considering the results of this experiment, the product design can be changed in order to avoid any defective welds. The defect shown in figure 15 can be a result of the lack of DFM considerations taken when designing the product. As stated before, large gaps between two pieces can cause difficulties in welding. This can be fixed with an interlocking design which allows for backing in order to complete a successful weld. A backing may provide extra material to fill any possible gaps that may be too large to weld. In order to avoid any further defects experienced in this project, Synergy can redesign the track bar brace in order to achieve a successful weld.

## *5.3 Limitations:*

Despite the results of this project, there were some limitations that did not allow for fully conclusive results.

First, the parameters used in the program were as followed:

Wire Feed Speed: 385 – 430 ipm

Power Setting (Voltage and Amperage): 3.0 – 3.5

Travel Speed: 12 – 26 ipm

These parameters resulted in satisfactory welds but only through visual inspections. The lack of resources and time did not allow for thorough break tests to be conducted. Although the resulting welds from these parameters were visually passed, structurally the welds could possibly not meet the required specifications. In addition to this, these parameters were only determined using ¼-inch steel. Using other materials or thicknesses, these parameters can prove to be useless and result in out of spec welds. Therefore, further experimentation must be done when using different materials or thicknesses.

Next, these experiments were conducted only using one robot, the Fanuc 50iD. When using other robots, these parameters can be completely different especially the power which was only quantified as one numerical value through the Fanuc. If Synergy considers alternative robot brand options, these parameters must be tested before implementing them in full production.

Finally, as stated before, the prototyped fixture used in this project lacked the full design features included in the CAD model. The lack of funding and fabrication resources inhibited the production of a fully functional and precise fixture. Therefore, the out of spec results experienced through this production run could not conclude the functionality of the designed fixture. A proper fixture must be fabricated and tested in order to determine its effectiveness.

## VI. Economic Analysis

### *6.1 Future State Analysis 1:*

One alternative option of upgrading Synergy's welding process is to do nothing. The benefits of this option would be that it does not require any capital costs such as purchasing the robot, programming the robot, and manufacturing a fixture for the robot. Taking into consideration Synergy's current output with their existing process as shown below:

35 hours / week labor

4 minutes and 21 second cycle time

35 hours / 4 minutes and 21 seconds = **483 parts / week**

This results in 483 parts / week which can easily meet their demand of 7,200 parts per year. Realistically, Synergy needs to allocate their resources towards producing other parts that they sell so this number is the ideal production output.

Additionally, Synergy stated that their demand is increasing substantially with every year. This means that doing nothing will ideally satisfy this demand but only in the short term. If Synergy's demand continues to increase, they must redesign their process in order to keep up with increasing demand.

### *6.2 Future State Analysis 2:*

The final recommendation that is concluded through this report is to implement a robot welder. The benefits of an automated welding process would include faster cycle time, consistent and repeatable process reducing defects, and lower labor costs. The faster cycle time was discovered through this project by comparing the automated cycle time versus the manual cycle time which was shown to be a 30.2% improvement. This would help Synergy meet their rapidly increasing demand in the future. As shown below, if Synergy implemented the automated their welding process, their new demand would be as follows:

35 hours / week labor

2 minutes and 30 second cycle time

35 hours / 2 minutes and 30 seconds = **840 parts / week**

With the automated process being implemented, the new demand would be 840 parts / week which is a 42.5% improvement compared to the manual welding process. Based on these calculations, the extra one minutes saved by the automated process can add up quickly and surpass the output of the manual process. This will allow Synergy to keep up with their rapidly increasing demand.

In addition to this new demand, Synergy can now allocate its resources to other processes. This means that the automated process does not require a skilled welder to operate. With this resource now available, Synergy can use its skilled welders to produce new parts. With that being said, the demand of 840 parts / week achieved by the automated process is more achievable than the demand of the manual process due to the requirement of a skilled welder.

Although Synergy will achieve faster cycle times increasing their total output, the automated process does require intensive tooling design in order to make the process repeatable. As discovered through this project, the welding robot is very consistent if it was the proper tooling. The downside is that the robot does not know where the part is exactly and will continue with its program even if the part is not located properly. This issue can be solved through excellent tooling design that ensures proper location of the part for every cycle. In order to achieve this, it requires additional capital cost and time in order to have the process be very repeatable. The requirements would be a fixture that is accurately located with respect to the robot. Along with being accurately located, the fixture must be secure avoiding any potential movements that may push the fixture away from its location. The recommended procedure would be to have the robot and the fixture secured to a table which would ensure accuracy and repeatability of the process with every cycle.

Finally, along with the benefits of repeatability and increased output, implementing an automated welding process can reduce labor costs and free up resources in order to be allocated towards other processes. The manual welding process that Synergy currently has requires a skilled welder throughout the whole cycle. The welder is required to fixture the part, weld the part, and inspect the part. Normally, a skilled worker such as a welder has higher labor costs than non-skilled operators. With this benefit, Synergy does not require a skilled welder for the process if the welding process is automated. Synergy can hire a non-skilled operator for the automated process which would save labor costs and allow them to allocated their resources elsewhere.

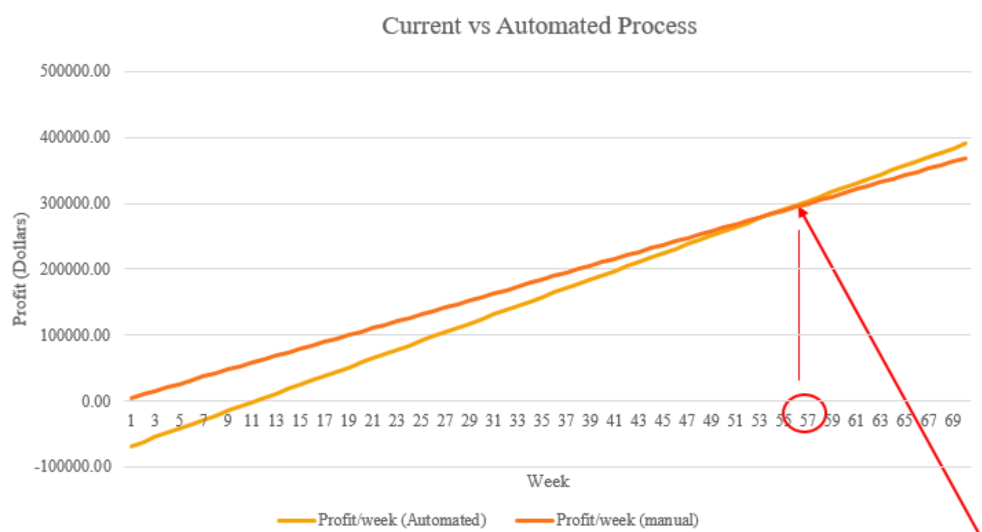
*6.3 Economic Justification:*

In the case that Synergy implements a robot welder, more specifically, the Fanuc 50iD robot welding system, the economic benefits include an increase in production output along with cost savings due to the elimination of skilled labor.

On page 38, you can see a break even analysis comparing Synergy's current process versus the automated process. Taking into consideration the labor costs, capital costs, labor hours, and profit / part, Synergy will break even at about 57 weeks. This means that if Synergy were to purchase a welding robot for $76,000, in order to earn this capital back along with catching up to the profit of the manual process, it would take about 57 weeks. In addition to this, after 57 weeks, the profit from implementing a robot welder will continue to pass the profit rate of the manual process. In short, after earning back the capital, the welding robot will continue to increase profits due to the elimination of skilled labor benefiting Synergy after about 57 weeks.

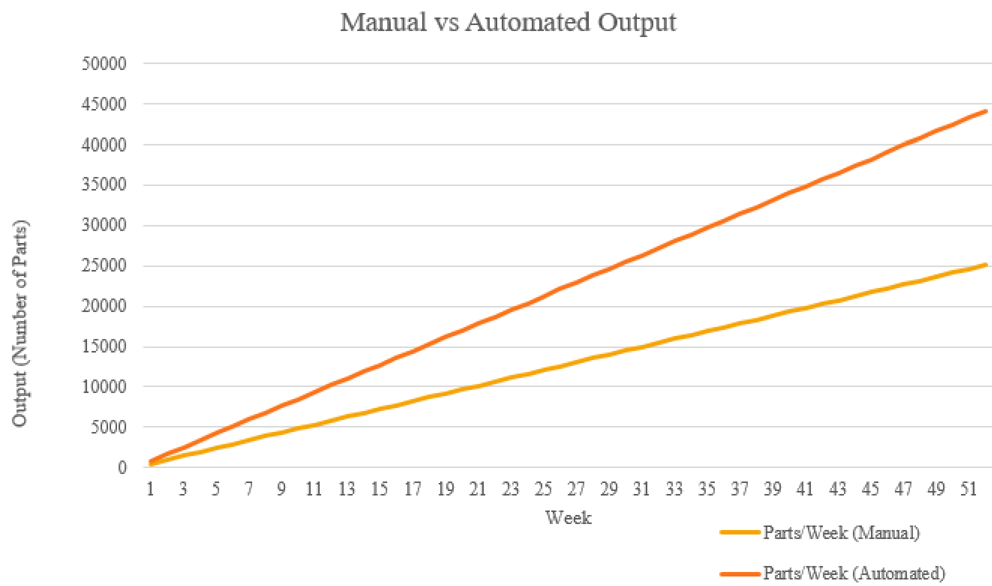
Additionally, based on the information gathered, implementing a robot welder will increase the output production due to the lower cycle time. If the entire system is fully automated, on top of the lower cycle time, the robot can operate 24 hours/day. Although this was not studied in this project, this would immensely increase output but it would require a higher capital due to the high price of automation equipment. Focusing on solely the robot welder, Synergy will still experience a 43.1% increase in output. This would result in about 43,000 parts produced annually based on a weekly work schedule of 35 hours/week. This study is conducted based on the operator and robot costs only. Before considering this benefit, there are more costs that must be taken into account. For example, you cannot just install a robot welder and expect it to be welding parts the same day. It takes time to program the robot and figure out the ideal parameters. Based on this project, the time spent programming was roughly one week. For Synergy, this would require an engineer and one week's salary in order to develop the proper program. In addition to this, tooling costs and manufacture time must be taken into consideration. The more complicated a part is, the longer it takes to manufacture and design the fixture along with the high cost to manufacture it. This also requires a skilled engineer that must be paid for however long this work takes.

Overall, implementing a robot welder has many factors that must be taken into consideration. Based on this study, the robot welder prevails to be a great option increasing output and returning the initial investment in a reasonable amount of time. Before Synergy considers implementing a robot welder, all of the factors such as part complexity, fixture design, and labor costs must be estimated in order to confidently conclude the benefits of implementing a robot welder.




- Using:
  - Demand = **7,200 parts/year**
  - Total Labor cost for manual welding process = **$25/hr**
  - Total Labor cost for automated welding process = **$15/hr**
  - Total cost of robot = **$76,000**
  - **$38 profit/part** using manual welding process
  - **$48 profit/part** using new automated process (eliminating labor cost)

Break Even Point at about 57 weeks




- Using:
  - **35 Hours per Week**
  - Automated cycle time =
    - **2 min 30 seconds**
  - Manual cycle time =
    - **3 min 30 seconds**

At 52 weeks:
Manual: **24,633**
Automated: **43,325**

**43.1%** Increase in yearly output

## VII. Conclusion

The objectives of this project were to analyze the benefits and issues of implementing a robot welder, more specifically, the Fanuc 50iD. This was due to the current issue of meeting demand that Synergy is facing. With Synergy experiencing a rapid increase in demand from 2016 to 2017, a viable solution would be to implement a robot welder. Synergy wanted to analyze the benefits of implementing a robot and address the question of, "Is it beneficial to implement a robot welder based on our current demand and resources?" With this issue, this project addressed the following:

- Synergy will experience an increase in production when implementing a robot welder due to the 30.2% improvement in cycle time.
- Synergy will experience a reasonable payback period of 57 weeks based on ideal calculations.
- Synergy's profits will increase by $10 per part due to the elimination of skilled labor.
- There must be further measures and considerations taken when implementing an automated welding process. More specifically, fixture design, engineering cost and time, and tooling setup and costs.

Finally, based on these findings, the recommendation would be to purchase and implement a robot welder. This is due to the significant improvement in cycle time, consistency, and reduction in labor costs. Although this would be a great option, Synergy must take many outlying factors into consideration such as fixture design, engineering cost and time, along with tooling setup and costs. In addition to this, another recommendation would be to professionally manufacture the fixture and, most importantly, test the fixture to ensure that it provides precise location for every cycle. As previously stated, it was discovered that the fixture did not provide precise location for every cycle which led to many defects. If a fixture is designed well and professionally manufactured, along with providing a solid location every cycle, the implementation of the automated process will be successful.

The key lessons taken from this project were the wide range of considerations that must be taken in order to implement and automated process. Along with this, it was discovered that precise location and fixture design play a vital role in automation. Without a proper fixture and location, the process can be prone to many defects.

Finally, looking back, the additional measures and steps that would be taken to ensure thorough results from this project would be:

- Conduct break tests in order to confirm structural integrity of welds.
- Conduct a long term analysis of a robot welder implemented in order to determine requirements needed.
- Look into computer software to program the robot.
- Acquire more material in order to test parameters thoroughly.

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